



ARCHES NATIONAL PARK RESEARCH SUMMARY 2009

1) Study Title: Phylogeny and Evolutionary History of *Anticlea vaginata* Rydb. (Melanthiaceae): A Hanging Garden Endemic

Permit No.: ARCH-2009-SCI-0001

Principal Investigator: Tina Ayers

Purpose of Scientific Study: Sheathed Death Camas, *Anticlea vaginata* Rydb. (Liliales: Melanthiaceae) is a rare hanging garden endemic species. This research will add to the body of knowledge about Colorado Plateau hanging garden endemic plant species, assist with the on going endeavor to resolve the complicated taxonomy of the genus *Anticlea*, and assist agencies in future land management decisions involving this species. Knowledge of genetic diversity within populations will suggest which populations are particularly important to protect, and knowledge of gene flow will indicate what hanging gardens, if any, are interacting as subpopulations and which are completely isolated.

This research will address the following questions:

Is *Anticlea vaginata* a distinct taxon?

What is the most likely geographic and biological origin for *Anticlea vaginata*?

Is there gene flow between isolated populations of *Anticlea vaginata* and between *A. vaginata* and *Anticlea elegans*, or does there appear to be continuing diversification? Which populations of *Anticlea vaginata* exhibit the highest levels of genetic diversity, recommending them for future conservation?

What pollinators are visiting this species and which ones seem to be the most important to its fecundity?

Findings/Accomplishments for 2009: Sheathed Death Camas, *Anticlea vaginata* Rydb. (Liliales: Melanthiaceae) is a rare, hanging garden endemic plant species. *Anticlea vaginata* occurs from Dinosaur National Monument south to Arches NP, Canyonlands NP, Natural Bridges NM, and Glen Canyon NRA. There is also one population in Zion NP, one in Grand Canyon NP, and a few in northeastern Arizona on the Navajo Reservation. Very little research has been conducted on this unique species. In order address *A. vaginata*'s validity as a species, amounts of gene flow between populations, and levels of genetic diversity, a combination of molecular data, physical characteristics, and life history traits are being analyzed. For two populations, one leaf from each of 15 individuals was collected for genetic analysis. Pollinators were collected at the same time as leaf collection, resulting in ten potential pollinators being captured for identification. One entire plant was collected from one population to be a voucher specimen and to be included in the analyses of physical characteristics. Genetic and morphological analyses are in progress. Identifying whether or not *A. vaginata* is a good species, knowing its levels of genetic diversity and gene flow, and understanding its basic life history traits will all assist in its management.

3) Study Title: Soil Survey of Arches National Park, Utah

Permit No.: ARCH-2009-SCI-0003

Principal Investigator: Victor Parslow

Purpose of Scientific Study: To provide an updated soil and ecological site inventory for Arches National Park (ARCH), that meets National Cooperative Soil

Survey (NCSS) standards and park management and planning needs. The existing soil survey was conducted in the late 1970's and the early 1980's as part of the Grand County, Utah soil survey. This inventory was primarily designed as a tool in managing grazing lands and has been found to be too general to be useful for managing the park. Information is lacking to model salt movement, mitigate visitor impacts, identify and protect habitat of Threatened and Endangered species, and other park responsibilities. In 2003, representatives of the National Park Service approached the Natural Resources Conservation Service to update the soil survey within Arches and Canyonlands National Parks and Natural Bridges and Hovenweep National Monuments. The plan of work and contract were approved in 2004. This application is seeking permission to carry out the necessary field work to complete the contract.

Findings/Accomplishments for 2009: No field activities were conducted during this year; a draft soil survey has been produced.

5) Study Title: Delicate Arch Trailhead Restoration Project

Permit No.: ARCH-2009-SCI-0005

Principal Investigator: Tamsin McCormick

Purpose of Scientific Study: The proposed habitat enhancement project is part of a larger effort by our conservation organization toward improving wildlife habitats along critical waterways in the high deserts at the heart of the Colorado Plateau. We hope to increase public awareness about the consequences of recreation impacts and unchecked noxious weed invasions and how members of the public can be a part of the solution, while performing hands-on restoration of a degraded riparian area in Arches National Park. We have targeted the area of the Delicate Arch trailhead, a major international tourist destination, to launch a demonstration project. The project includes rehabilitating areas adjacent to Salt Wash near Wolfe Cabin. Efforts in 2009 focused on revegetation of disturbance sites following relocation of the trailhead toilets in summer, 2009. The scope of work was coordinated with NPS Resource Management staff. Plant collection protocols are included in this permit.

Findings/Accomplishments for 2009: Disturbance areas identified for revegetation in 2009 included the old toilet pad, which was covered with sandy soil brought in by the NPS (approximately 200 square meters), and social trailing between the main trail and old toilet site (approximately 300 square meters). These areas were planted with 200 one- to five-gallon live plants collected from private and BLM lands within 50 miles of the Park. Planting took place on October 8-9 and November 4, 6, and 23. All transplants were hand-watered weekly through November 23 during weeks with no precipitation. On planting days, staff engaged several members of the visiting public in discussions about the need for the project and the materials selected for planting. Challenges to success of this revegetation project included disturbance in the site, from large animals and visitors and foraging by rabbits, especially of rabbitbrush, globemallow and to a lesser extent, saltbush. This was a particularly dry Fall, and the plants were relatively lush when installed compared with surrounding vegetation. The main social trail was an old roadway that had previously been revegetated by NPS, although only ephedra and yucca obviously remain from this previous planting. The soil was extremely compacted in this area, especially below about nine inches from the surface. It is likely that this roadway had been driven extensively when wet, compacting the fine-textured soils. This hard layer at depth may be a challenge for many of the grasses that were planted, although holes were dug at least nine inches deep and the soil amended. Approximate numbers, by species, planted in the old toilet pad and the visitor impact areas respectively, are as follows:

Grasses:

Sporobolus cryptandrus (30,19)

Stipa hymenoides (6,28)

Aristida purpurea (0,4)

Forbs:

Sphaeralcea parvifolia (10,15)

Machaeranthera canescens (5,5)

Grindelia fastigiata (1,6)

Shrubs:

Atriplex canescens (>9, >7; 21 total)

Gutierrezia sarothrae (14,10)

Artemisia tridentata (4, 6)

Artemisia filifolia (4, 6)

Chrysothamnus nauseosus (3, 5)

Ephedra viridis (5, 2)

Other forbs identified for revegetation included *Astragalus* spp. and *Oenothera pallida*, which we hoped to collect in the Park, but which were not available. The grass *Sporobolus airoides* was also identified as a possible grass to split from existing grasses, but we chose not to disturb existing healthy grasses at this point, in view of the soil type. Some additional planting, watering and weeding are planned for spring, 2010.

6) Study Title: Carbon and Nitrogen Cycles in Arid Lands: The Role of biological Soil Crusts as Influenced by Soil Surface disturbance, Climate Change and Annual Grass Invasion

Permit No.: ARCH-2009-SCI-0009

Principal Investigator: Jayne Belnap

Purpose of Scientific Study: Models indicate the presence of a large carbon (C) sink at temperate latitudes in the northern hemisphere. Over thirty percent of lands both globally and in the United States consist of semi-arid or arid landscapes. Very little is known about carbon dynamics in these regions. Biological soil crusts, composed primarily of cyanobacteria, algae, lichens and mosses, can completely cover plant interspaces in undisturbed areas, and constitute 70 percent or more of the living ground cover. These soil crusts can be the dominant source of nitrogen (N) for vascular plants. They fix C at a high rate and are critical for soil stability and aggregate formation, which is important in C storage. They also absorb significant amounts of CH₄. In areas where precipitation is low and soils have low fertility, native plants often rely on intact biological soil crusts to provide increased water and nutrient flow to the broadly scattered vegetation. Thus, there are many ways in which biological soil crusts influence biogeochemical cycles and the structure and productivity of the vascular plant community. Soil surface disturbance, invasive plants, and climate change have the potential to dramatically alter the structure and function of biological soil crusts. The current combination of recreational use and livestock grazing is resulting in unprecedented levels of surface disturbance on many arid lands. In regions that did not have substantial amounts of surface disturbance in the Holocene, biological soil crusts disappear readily when trampled by animals or vehicles. Exotic annual grasses are invading many of these areas. Trampling and invasion results in reduced cover and changes in the species composition of biological soil crusts. This, in turn, leads to changes in processes such as decomposition, N and C fluxes, soil moisture, and nutrient availability to vascular plants. Decreases of only 1 percent of soil organic carbon in the top 10 cm of rangeland soils is equivalent to the total C emissions from all croplands nation-wide. Changes in climate regimes, such as a shift in the summer monsoonal boundaries in the western United States, are expected to influence the composition and

physiological functioning of biological soil crusts. Various crust components have different photosynthetic and respiration responses to temperature and moisture. In addition, different crusts have different methane fluxes. Therefore, changes in the timing or amount of temperature and precipitation is expected to alter soil C and N fluxes through changes in physiological response or crustal composition. This, in turn, can significantly impact vascular plant productivity. This project will establish how alterations in species composition by surface disturbance, invasive grasses, and/or climate change may affect N and C inputs and fluxes, in different soils under different climatic regimes. Because current and expected changes in land use and climate will occur over millions of acres in western rangelands, impacts to soil crusts have the potential for dramatically affecting C cycles, N cycles, and vascular plant productivity over much of the western United States. In addition, semi-arid and arid ecosystems represent over one-third of the Earth's terrestrial surface, and most are covered by biological soil crusts. As human impacts are escalating both regionally and globally in these drier regions, the research questions posed in this proposal have significant implications for global C budgets as well.

Findings/Accomplishments for 2009: With this ongoing project, we are continuing to maintain our experimental plots and collect data. As we are looking at long-term effects of soil surface disturbance, we will continue to annually monitor change, and analyze data in the future.

7) Study Title: Impacts of Climatic Change and Land Use on the Southwestern U.S.
Permit No.: ARCH-2009-SCI-0007

Principal Investigator: Jayne Belnap

Purpose of Scientific Study: (1) the causes and timing of changes in alluvial environments (rivers, streams, hillslopes), such as flooding, the cutting and filling of arroyos, and sediment discharge; (2) the role of eolian dust for soil fertility, invasion of exotic species, hydrology, and surface stability in deserts; (3) the interaction of physical and biologic processes critical for ecosystem functions; (4) how climate in the southwest has varied over decades, centuries, and millennia; (5) how future climatic variations will affect the Southwestern land surface (in terms of erosion, sand-dune activity, dust-storm frequency, flooding, landslides,); (6) how past climatic changes and environments affected prehistoric cultures.

Findings/Accomplishments for 2009: This is a long-term project, with which we hope to understand climatic variability and its effects on dust projection and soil fertility. Multiple years will be required to capture the full range of variability so that we may better understand the role of extreme events, as well as normal regimes.

8) Study Title: Firewood movement across state lines by national park visitors

Permit No.: ARCH-2009-SCI-0008

Principal Investigator: Betsy Goodrich

Purpose of Scientific Study: The purpose of this study is to quantify the number of campers visiting national parks in four western states (Colorado, Arizona, Utah and Wyoming) who are bringing firewood from out-of-state sources. This survey is one objective of a larger research project to assess the risks of transporting invasive forest pests (insects and pathogens) from state to state in the Rocky Mountain region. The research is also a part of a nationwide education effort to reduce these potential risks on a state to state basis. Surveying park visitors (campers) will help us determine the risk of invasive species importation via firewood and help us direct our education and management actions. This project is in cooperation with the Colorado Department of Agriculture and USDA-APHIS.

Findings/Accomplishments for 2009: We quantified the number of campers visiting 30 campgrounds in 13 National Parks and National Recreation Areas in the

southern Rocky Mountain region (Arizona, Nevada, Colorado, Utah and Wyoming). A survey was conducted in one campground in Arches NP (Devils Garden), one campground in Black Canyon of the Gunnison (South Rim), two campgrounds in Bryce (North and Sunset), one campground in Capitol Reef (Fruita), one campground in Glen Canyon NRA (Wahweap), two campgrounds in Grand Canyon NP (Desert View and Mather), six campgrounds in Grand Teton NP (Colter Bay, Flagg Ranch, Gros Ventre, Jenny Lake, Lizard Creek and Signal Mountain), one campground in Great Sand Dunes NP (Pinyon Flats), five campgrounds in Lake Mead NRA (Boulder Beach, Calville Bay, Echo Bay, Las Vegas Bay and Temple Bar), one campground in Mesa Verde NP (Morefield), three campgrounds in Rocky Mountain NP (Aspenglen, Glacier Basin and Moraine Park), four campgrounds in Yellowstone NP (Bridge Bay, Canyon, Grant and Madison) and two campgrounds in Zion NP (South and Watchman).

In Arches NP, 18 campers were surveyed during May, 2009. Visitors were asked if they had firewood, where it was from (state source), where they obtained the firewood (wood source: from a local vendor in the park, nearby retail, cut or collected at home, lumber scraps or other) and if it was a conifer or hardwood species (if known). If the camper was willing to let us inspect the wood, details on the appearance were recorded (bark presence, evidence of previous infestation by insects and fungal contamination). In addition, we distributed educational posters and information to campground hosts and park staff, when available.

Over all national parks, we visited 4,522 campsites and 1,658 of these campsites were surveyed with visitors present. The preliminary results indicate 1,116 campers had firewood and 36% of the wood was coming from out of state. Of the 36% of campers with firewood from out of state, 12% of the campers were from the park state, 48% were from a neighboring state and 40% were from farther away. Based on NPS visitor statistics from 2008, this equates to 330,575 campers potentially bringing firewood from out of state. The results varied by state: 23% of campers in Arizona parks brought firewood from out of state, 8% of campers in Colorado parks, 43% of campers in Nevada parks, 57% of campers in Utah and 24% of campers in Wyoming. Of campers with firewood from all parks, 32% of the firewood was purchased inside the park, while 25% was purchased outside the park and 17% was cut or collected from the camper's home and transported to the campsite. Sixty-seven percent of the firewood was conifer with 7% hardwood. Fifty-three percent was found to have presence of previous insect (beetles and borers) infestation while 39% was found to have presence of previous fungi (stain and decay fungi) infestation. Data collection is completed and we are continuing to analyze data and prepare a refereed manuscript.

9) Study Title: The three-dimensional geometry and kinematics of brittle structures within the immediate hanging-wall of large extensional faults:

Implications for subsurface hydrocarbon migration and entrapment

Permit No.: ARCH-2009-SCI-0009

Principal Investigator: Stuart Clarke

Purpose of Scientific Study: In the past few years, the focus of research in to the effects of faults on hydrocarbon migration has shifted from the study of single faults to encompass the geometrical relationships between spatially limited but kinematically linked faults, and the effects that related structures such as deformation zones at tip points, relay ramps and fault linkages may have on migration. A number of recent studies (e.g.: Rotevan et al., 2007; Johansen et al., 2005; Fossen et al., 2005; Berg & Skar, 2005) have examined the development of damage zones (deformation bands, joints and sub-seismic scale faulting) associated with en-echelon faults, relay ramps and splay faults. This study will examine the

structural geometry and detail of a number of sub-seismic-scale, en-echelon fault segments and related structures that are well-exposed within the hanging-wall of a large, seismic-scale, extensional fault within the Cache Valley, Arches National Park, Utah, U.S.A. The study will examine the accommodation of strain within the hanging-wall to investigate the development of these sub-seismic extensional structures in relation to deformation on the seismic-scale fault. Fully balanced structural models will be developed and their analysis will allow the prediction of sub-seismic-scale brittle structures in the hanging-wall blocks of seismic-scale faults from the observed displacement parameters on these larger structures. These smaller-scale structures, and their relationships to larger scale structures are of particular relevance in subsurface hydrocarbon reservoirs because of their effects on hydrocarbon migration: the smaller scale structures are below the resolution resolvable of seismic survey and therefore cannot be imaged directly in such settings.

Findings/Accomplishments for 2009: The fieldwork aspect of this research project was completed in September 2009. Statistical analysis of the results and construction of a preliminary three-dimensional model is on-going and expected to be completed in the 1st quarter of 2010.

10) Study Title: Three-Dimensional Characterisation of Faults and Their Influence on Fluid Migration.

Permit No.: ARCH-2009-SCI-0010

Principal Investigator: Stuart Clarke

Purpose of Scientific Study: Research to study the effects of faults on the migration within, and subsequent extraction of hydrocarbons from, sedimentary basins on basin- field- and trap-scale.

Findings/Accomplishments for 2009: The fieldwork aspect of this research project was completed in September 2009. Construction of a preliminary three-dimensional model for field data is on-going and expected to be completed in the 1st quarter of 2010.

11) Study Title: Annual Forest Land Inventory of Utah

Permit No.: ARCH-2009-SCI-0011

Principal Investigator: Renee O'Brien

Purpose of Scientific Study: The Interior West Forest Inventory and Analysis program is responsible for statewide inventories in eight states. The purpose of this ongoing inventory is to gather information on condition and trends of forest resources to assess plant diversity; fuels and potential fire hazards; condition of wildlife habitats; mortality and risk associated with fire, insects, or disease; and biomass, carbon storage, forest health and other general characteristics of forest ecosystems. Under the annualized inventory system, each field plot is visited one every 10 years, with approximately 10 percent of the total plots visited each year within a state. The FIA program produces a fiveyear report for each State.

Findings/Accomplishments for 2009: As part of the Annual Forest Land Inventory of Utah, field crews visited two plots at Arches National Park during the 2009 field season. One of these plots met the Inventory's definition of forest land, and field crews performed a non-consumptive vegetation inventory on this plot. The results of this ongoing inventory are periodically updated and made available at www.fs.fed.us/rm/ogden/publications/. The fiveyear report for the Utah inventory will be released in Spring 2010. Site-specific summaries of field data, in PDF form, will be sent to the designated NPS contact person.

13) Study Title: Determinants of geographic distribution in western North American monkeyflowers

Permit No.: ARCH-2009-SCI-0013

Principal Investigator: Seema Sheth

Purpose of Scientific Study: The goal of this research is to evaluate the roles of evolutionary and historical processes in shaping the geographic distributions of species. To do so, we are focusing on species of monkeyflowers that occur in western North America. Specifically, we are addressing two main objectives: 1) Limits to niche evolution: Evaluate whether adaptive genetic variation and response to selection are lower in marginal populations than in central populations within species, and lower in species with narrow niches than in species with broad niches; 2) History: Assess the relative roles of the vicariance and long-distance dispersal hypotheses in explaining geographic patterns of speciation. To determine whether reduced evolutionary potential at species' range margins limits species' responses to natural selection, our aim is to collect seed from *Mimulus eastwoodiae* populations and conduct artificial experiments to compare quantitative genetic variation between central and marginal populations within its range. To determine whether rare species are products of historical events, our goal is to collect leaf tissue from populations across the geographic range of *Mimulus eastwoodiae* to infer historical demography from patterns of genetic variation.

Findings/Accomplishments for 2009: We visited one population of *Mimulus eastwoodiae* in an alcove adjacent to the Delicate Arch Trail. We collected one fruit from each of two individuals in the population, and leaf tissue samples from each of 17 individuals in the population. We planted one fruit in the Colorado State University Greenhouse, but the fruit capsule appeared empty and there was no germination. We have not yet extracted DNA from leaf tissue samples. We may do additional collecting of *Mimulus eastwoodiae* fruits in Arches National Park in summers 2010 and/or 2011.

CANYONLANDS NATIONAL PARK RESEARCH SUMMARY 2009

1) Study Title: Phylogeny and Evolutionary History of *Anticlea vaginata* Rydb. (Melanthiaceae): A Hanging Garden Endemic

Permit No.: CANY-2009-SCI-0001

Principal Investigator: Tina Ayers

Purpose of Scientific Study: Sheathed Death Camas, *Anticlea vaginata* Rydb. (Liliales: Melanthiaceae) is a rare hanging garden endemic species. This research will add to the body of knowledge about Colorado Plateau hanging garden endemic plant species, assist with the ongoing endeavor to resolve the complicated taxonomy of the genus *Anticlea*, and assist agencies in future land management decisions involving this species. Knowledge of genetic diversity within populations will suggest which populations are particularly important to protect, and knowledge of gene flow will indicate what hanging gardens, if any, are interacting as subpopulations and which are completely isolated.

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2) Study Title: A Comparative Study of Online and In-Person Interpretation Effectiveness

Permit No.: CANY-2009-SCI-0002

Principal Investigator: Karen Henker

Purpose of Scientific Study: This study proposes to assess and compare the effectiveness of two forms of interpretive presentation: interpretive videos (available on a national park's website and in the same park's visitor center) and traditional ranger talks. It is expected that significant differences exist between actual and "virtual" park visitors in both the depth and nature of their responses – namely, that online viewers will retain key facts but demonstrate only moderate emotional responses while park visitors will respond more strongly to emotional triggers from both traditional and video programs because they are immersed in – and affected by

– the landscape.

This study could have real benefits for the park involved. Its results may be used to evaluate the success of the park's current interpretive plan, and to assess whether or not increased funding into the new "podcast" wave is justified. It is hoped this study will also add to the growing body of knowledge in interpretation research and advance the understanding of "new media" interpretation.

Findings/Accomplishments for 2009: This study assessed and compared the effectiveness of three kinds of interpretive presentation: online podcasts, the same videos seen at a park's visitor center (VC), and ranger-led programs. The two independent variables were program format (video vs. in-person) and viewing location (VC vs. online). After viewing one of the treatment presentations, visitors were asked to complete a survey in which they responded to eleven indicators of effective interpretation including: strength of emotional and intellectual reactions to the content, retention of the interpretive programs' key facts, and feelings of stewardship inspired by the programs. Basic demographic data were also collected. A total of 408 surveys were collected from 299 video viewers and 109 in-person attendees. Responses from in-park program viewers were only slightly - but statistically significantly - stronger than those of both podcast and VC video viewers for most indicator categories, especially their smiles ($p \leq .05$) and intent to change behavior ($p \leq .01$). Podcast responses were stronger than VC video responses, particularly for viewers' enjoyment, smiles, and level of personal interest ($p \leq .05$). Of the three treatments, VC videos generated the weakest viewer responses. Podcasts viewed online were effective methods for generating viewers' intellectual and emotional connections to park resources. Although in-person programs generated statistically stronger emotional and stewardship responses than interpretive videos, the differences were not practically significant (mean scores differed by less than 0.5 points). These results provide empirical evidence to justify parks' increasing investment in new media interpretation.

4) Study Title: Earthscope/USArray Transportable Array Seismic Station

Permit No.: CANY-2009-SCI-0004

Principal Investigator: Robert Busby

Purpose of Scientific Study: The USArray Transportable Array is an Earthquake monitoring system, operated and maintained by IRIS (a non-profit corporation of US universities) on behalf of the National Science Foundation. It uses continuously operating seismic stations to measure ground motion caused by earthquakes and volcanic processes.

Findings/Accomplishments for 2009: This station detected 1145 Regional earthquakes and 2177 distant earthquakes (occurring over 10 degrees or 1100 km from the station). The magnitudes of these earthquakes ranged from very small (magnitude < 2.0) which are not felt by humans anywhere, to large events which can result in significant destruction.

6) Study Title: National Rivers and Streams Assessment (NRSA)

Permit No.: CANY-2009-SCI-0006

Principal Investigator: Benjamin Brown

Purpose of Scientific Study: The purpose of the NRSA study is to sample wadeable and non-wadeable streams across the country using the same sampling methods to ultimately make a general assessment on streams of different orders across the country. The NRSA protocol was written by the EPA with the intent of making an assessment of the physical, biological, and chemical properties of

particular stream sites. All sites were picked at random. The State of Utah is conducting the research at the selected sites within the state for EPA.

Findings/Accomplishments for 2009: Using the NRSA non-wadeable stream sampling methods, two sites were sampled in Canyonlands National Park. One site was duplicated for QA/QC purposes. One site was on the Colorado River near Lathrop Canyon (sampled once in late April and once in September), and the other on the Colorado River near Spanish Bottom. All samples for Utah NRSA sites have been submitted to their appropriate labs, but analysis has not yet occurred. Analysis of samples will be an on-going task for the next several months before the data is released. For each site a variety of samples were collected including the following: water chemistry; enterococci (fecal indicator); fish tissue (heavy metal contamination); fish population counts; periphyton assemblage: ID, biomass, alkalinity-phosphate activity (APA), periphyton chlorophyll; water column chlorophyll; sediment chemistry/enzymes; macroinvertebrates; physical habitat assessments; an overall written general assessment. The physical habitat and general assessment data packets are available for people to view now, but no statistical analysis, review, or conclusions have been made with these data yet.

7) Study Title: Mycorrhizal Ecology in Host Plants with Contrasting Life history Traits

Permit No.: CANY-2009-SCI-0007

Principal Investigator: Catherine Zabinski

Purpose of Scientific Study: Arbuscular mycorrhizae (AM) are a plant-fungus symbiosis, in which the plant provides the fungus with a carbon source, while the fungus increases nutrient availability, especially phosphorus (P). Previous research on AM shows that the effect of this symbiosis on the host plant can range from positive (mutualistic) to negative (parasitic). A portion of our research focuses on AM in plants growing in the thermal areas of Yellowstone National Park. This research is important because we know very little about this symbiosis in extreme environments. Our research addresses the following questions: 1) Does the AM symbiosis function differently in extreme environments as compared to what has been documented in 'non-extreme' sites? 2) Are AM fungal species native to thermal soils unique species, unique ecotypes, or no different from AM fungal species on non-thermal soils? 3) Are mycorrhizal fungi specifically adapted to thermal site conditions, or does the range of genetic variability found in AM fungi naturally enable them to inhabit a broad range of environments, including thermal soils? This year we are expanding our research to mycorrhizal ecology of other extreme environments, either subject to high temperatures or low water levels. In these environments, and in thermal soils, we will ask the following question: 4) Do host plant life history traits affect the composition of the AM fungal community, specifically annual versus perennial host plants in extreme environments?

Findings/Accomplishments for 2009: Study sites were successfully located and cleared with park personnel during 2009. Preliminary sampling was also conducted in these study sites, and results are pending. Study sites will again be sampled during 2010.

8) Study Title: Soil Survey of Canyonlands National Park, Utah

Permit No.: CANY-2009-SCI-0008

Principal Investigator: Victor Parslow

Purpose of Scientific Study: To provide an updated soil and ecological site inventory for Canyonlands National Park (CANY) that meets National Cooperative Soil Survey (NCSS) standards and park management and planning needs. The existing soil survey was conducted in the 1970s and the early 1980s as part of the

Henry Mountains, Utah soil survey and the Canyonlands soil survey. These inventories were primarily designed as a tool for use in managing grazing lands and have been found to be too general to be useful in managing the park. Information is insufficient to model salt movement, mitigate visitor impacts, identify and protect habitat of Threatened and Endangered species, and other park responsibilities. In 2003, representatives of the National Park Service approached the Natural Resources Conservation Service to update the existing soil surveys within Arches and Canyonlands National Parks and Natural Bridges and Hovenweep National Monuments and the Orange Cliffs section of the Glen Canyon Recreation Area. The Plan of Work and contract were approved in 2004. This application is seeking permission to carry out the field work necessary to complete the contract.

Findings/Accomplishments for 2009: 1. Soil Survey Activities: Soil survey activities were conducted in Canyonlands in 2009. Transects of the landscape were conducted, and soil descriptions and plant inventory data were recorded. 15 soil samples were collected. These samples have been catalogued, and are stored in the Richfield USDA Service Center.

2. Archaeological activities: As a result of the field work of 2009, 6 archaeological sites as well as 6 isolated occurrences were recorded in Canyonlands. Cultural material was collected from 5 sites. Details of these resources including locations and descriptions of their contents can be referenced by contacting the SEUG office in Moab, Utah. All cultural resources were successfully avoided. No cultural material was unearthed during the course of soil sample collection.

10) Study Title: Hydrology and geomorphology in Arid River Systems:
A Case Study in Canyonland Country (Evaluation of vehicle impacts in Salt Creek)

Permit No.: CANY-2009-SCI-0010

Principal Investigator: Anne Brasher

Purpose of Scientific Study: To study the hydrology and geomorphology of the Salt Creek watershed in the Needles District of Canyonlands National Park. This study seeks to understand linkages among hydrologic, geomorphologic, and riparian characteristics to help predict stream health and stream channel trends in arid river ecosystems. The study will look at natural versus anthropogenic impacts to the stream.

Findings/Accomplishments for 2009: Results of this study were published as part of Stephen Hunter's Master's thesis at the University of Wyoming. A hard copy will be provided to the park and is available at the following ftp site:
<ftp://ftpext.usgs.gov/pub/wr/ut/moab/brasher/Salt Creek Geomorphology>.

11) Study Title: NCPN Integrated Upland Monitoring in Canyonlands National Park

Permit No.: CANY-2009-SCI-0011

Principal Investigator: Dana Witwicki

Purpose of Scientific Study: The Northern Colorado Plateau Inventory and Monitoring Network (NCPN) of the National Park Service has identified upland ecosystem characteristics, processes, vegetation, and other biota as vital signs to be monitored. Upland monitoring is intended to strike a balance between increasing fundamental understanding of dryland systems and providing managers early warning of undesirable change. It will document the variability in these systems while providing information needed for resource management decisions.

Addressing these two goals will be accomplished partly through sampling design and data analysis. Some sites may be selected as representative of large portions of the landscape, others because of their management history. Evaluation of upland monitoring data in relation to other vital signs will facilitate identification of drivers and distinguishing "natural" from anthropogenic change.

Additionally, plot data from this effort will be used in the classification and interpretation of remotely sensed data. NCPN upland monitoring objectives for selected ecological sites:

1. Determine annual status and trends in ground cover (live and standing dead vegetation, litter, rock, biological soil crust, and bare ground); spatial pattern of vegetation by life form; soil aggregate stability and compaction as indicators of soil/site stability; hydrologic function, and nutrient cycling.
2. Determine annual status and trends in cover of biological soil crusts by species or morphological group.
3. Determine annual status and trends in cover of exotic plants in upland areas.

To better evaluate monitoring methods and objectives, the NCPN proposes to implement a three year pilot study at CANY. This will be the final year of the pilot study.

Findings/Accomplishments for 2009: The first three years of upland data were analyzed and presented to the park in a final report for the pilot study. A long-term operational sampling design was created and implemented for the 4th year of upland monitoring. A total of 48 plots were sampled in FY09, including 12 blackbrush, 12 PJ/blackbrush, and 24 grassland plots. Nine of the plots were revisited from the pilot study and 39 new plots were established. Monitoring will continue based on the long-term sampling design in FY10. An annual report describing 2009 plot data will be provided to the park.

12) Study Title: Monitoring the Colorado pikeminnow population in the mainstem Colorado River via periodic population estimates

Permit No.: CANY-2009-SCI-0012

Principal Investigator: Douglas Osmundson

Purpose of Scientific Study: To periodically provide population estimates of the Colorado River population of the endangered Colorado pikeminnow. Such estimates were made during 1991-1994, 1998-2000, and 2003-2005. Summary reports were produced following each of these three-year field efforts. Our office initiated a new three-year study beginning in 2008. Field work will end in 2010 and a summary report will be completed in 2011. The next three-year effort will begin in 2013. The study area extends from Palisade, Colorado to the confluence with the Green River in Utah (185 miles). The lower 40 miles of the study area is within Canyonlands National Park.

Findings/Accomplishments for 2009: In 2009, four complete passes were made through the upper and lower reaches as planned; in addition, a fifth pass was completed in the upper reach. Sampling was conducted from April 1 through June 24. Numbers of fish captured were similar to 2008. In the upper reach, there was a mean of 19 Colorado pikeminnow captured per pass (93 total); in the lower reach, a mean of 24 pikeminnow were captured per pass (95 total). Total within-year recaptures in the upper reach were higher in 2009 (11) than in 2008 (five), but in the lower reach, total within-year recaptures were fewer in 2009 (seven) than in 2008 (10). In both 2008 and 2009, the duration of spring runoff was especially long and made for good electrofishing and backwater netting conditions. In 2008, there were 41 boat-days expended on trammel-netting compared to 37 in 2003, three in 2004, and 41 in 2005. In 2009, there were 37 boat-days expended on trammel-netting. So lack of backwaters cannot account for the lower numbers of captures

in the past two years. Subtracting the number of captures attributable to the bass removal effort (Project No. 126), the total number of pikeminnow captured in 2005 was 319 (four passes in upper reach; five passes in lower reach). In contrast, the total captured in 2008 was 185 (five passes in upper reach; four passes in lower reach), or 42% less than in 2005. Similarly, in 2009 there was a total of 188 pikeminnow captured (five passes in upper reach; four passes in lower reach), or 41% lower than in 2005. During 2003-2005, there was a large group of young Colorado pikeminnow detected that was attributed to a strong year class produced in 1998 (see Osmundson and White 2009). No such strong year class was detected in 2008 or 2009. In addition, probability of capture was found to vary fairly substantially among years, in part explaining the higher numbers of fish captured in 2005 than in 2003 or 2004. Hence, the 41-42% lower number of pikeminnow captured in 2008 and 2009 than in 2005 cannot be ascribed at this time to the population declining by such amounts, but instead may be a function of lower probabilities of capture. Until program MARK is used to analyze the data, caution must be exercised when interpreting these numbers of total captures. Unlike in 2004 and 2005, when pikeminnow handled in July during the subsequent bass removal effort were added to the third pass of the upper reach (2004) or provided a fifth upper-reach pass (2005), no such pikeminnow were captured during the bass removal project in 2008 and 2009 that might have been used here to supplement captures. Pikeminnow seen during bass electrofishing were allowed to escape without capture or handling in an effort to minimize stress during the spawning season. For sampling within Canyonlands NP alone (river miles 0-34), there was a total of 27 Colorado pikeminnow captured and released in 2009. To date, data from 2008 and 2009 have been entered into Excel and checked for errors. However, no preliminary estimates of population abundance or other vital rates are available.

13) Study Title: Atmospheric Dust deposition to Canyonlands National Park

Permit No.: CANY-2009-SCI-0013

Principal Investigator: Jayne Belnap

Purpose of Scientific Study: The purpose of installing a total suspended particulate (TSP) sampler at Island in the Sky, Canyonlands National Park is to quantify the transport of windblown dust and to characterize the temporal variations in the chemical composition of this dust. Dust is a major atmospheric contaminant and a primary cause of reduced visibility in National Parks and other Class 1 airsheds. Despite the importance of dust to air quality and visibility, the sources, variability and composition of dust is not well understood. Accordingly, we are proposing the installation of a dust collector at Island in the Sky in CNP in order to develop a long-term dataset on dust deposition to the park. There are many factors that control the emission of dust from arid ecosystems including both land-use and climate. However, in order to better assess the quantity of material that is moved as well as its geochemical composition, we need the ability to regularly collect samples of suspended dust. The proposed sampler will provide a tool for the collection and chemical analysis of dust on a regular timescale and will greatly improve our estimates of dust fluxes to and from Canyonlands NP. The TSP sampler is a simple instrument that allows for the high volume filtration of suspended particulates. It consists of a 7.0 amp pump motor that is housed in an aluminum enclosure, resembling a large birdhouse. The pump pulls air over the lip of the aluminum enclosure through an 8" x 10" filter paper. The physical barrier provided by the lip prevents large objects such as leaves or insects from being collected on the filter but does allow the collection of a large range of particle sizes. In comparison with other common aerosol sampling equipment, such as those used by the IMPROVE network, the TSP is able to collect a more representative sample of suspended dust.

Additionally, because the TSP rapidly samples high volumes of air, more concentrated samples can be collected. The flux of dust from Canyonland ecosystems has important ecological implications. Dust is generated from the wind erosion of surface soils and this process is most extreme in arid and semi-arid ecosystems. Both the removal and subsequent deposition of dust can influence the ecosystem nutrient cycling and productivity. For example, the removal and/or redistribution of surface soils in arid ecosystems have been shown to alter the nutrient composition of surface soils and to influence the heterogeneity in vegetation composition. Additionally, dust exported from the arid southwest can be represent and significant input of materials to downwind ecosystems as far away as the Rocky Mountains.

Findings/Accomplishments for 2009: Dust collector is maintained, and samples are regularly collected by NPS personnel.

14) Study Title: The Role of Biological Soil Crusts in soil nutrient cycles as Influenced by Soil Surface Disturbance, Climate Change and Annual Grass Invasion
Permit No.: CANY-2009-SCI-0014

Principal Investigator: Jayne Belnap

Purpose of Scientific Study: This project will establish how alterations in species composition by surface disturbance, invasive grasses, and/or climate change may affect N and C inputs and fluxes, in different soils under different climatic regimes.

Findings/Accomplishments for 2009: With this ongoing project, we are continuing to maintain our experimental plots and collect data. As we are looking at long-term effects of soil surface disturbance, we will continue to annually monitor change, and analyze data in the future.

15) Study Title: Impacts of Climatic Change and Land Use on the Southwestern U.S.

Permit No.: CANY-2009-SCI-0015

Principal Investigator: Jayne Belnap

Purpose of Scientific Study: The population of the southwestern United States has grown rapidly over the past two decades and is projected to increase greatly over the next several decades. As the population has grown, climatic variations that would have affected relatively few people in the past will impact the lives of millions. Rapid and wide-spread climatic changes, such as those seen thousands and hundreds of years ago in the region and those projected for the future, may profoundly change the character of the region. Arid and semi-arid regions of the southwestern U.S. are among the most sensitive regions to changes in climate and land use, but the potential interactions between climatic change and land use are largely unknown (http://climweb.cr.usgs.gov/info/sw_new/swmap.html).

U.S. Geological Survey and collaborating scientists are seeking to understand how climate and how land use have influenced surficial geologic processes that modify landscapes and ecosystems. Such understanding is then used to model the landscape's response to future changes in climate and land use over time scales of seasons, of a few years, and of a few decades, so that information and interpretations can be applied by federal, state, and local agencies, as well as by Native American governments, for their land-use planning and management of resources. Project scientists work with ecologists, hydrologists, geographers, cartographers, and archeologists to address questions about (bold titles indicate activity at Canyonlands National Park):

(1) the causes and timing of changes in alluvial environments (rivers, streams, hillslopes), such as flooding, the cutting and filling of arroyos, and sediment discharge;

- (2) the role of eolian dust for soil fertility, invasion of exotic species, hydrology, and surface stability in deserts;
- (3) the interaction of physical and biologic processes critical for ecosystem functions;
- (4) how climate in the southwest has varied over decades, centuries, and millennia;
- (5) how future climatic variations will affect the Southwestern land surface (in terms of erosion, sand-dune activity, dust-storm frequency, flooding, landslides,);
- (6) how past climatic changes and environments affected prehistoric cultures.

General Project Goals

- Understand how past climatic change affected land surface: soil loss, fluvial erosion and alluviation, sand-dune mobilization, ecosystems, under time frames of past decades, centuries, and millennia.
- Understand today's interplay among climate, land use and surface processes (geologic and ecologic).
- Understand the impacts of future climate on land surface under the following time frames: seasons; El Niño/La Niña cycles; multiyear wet/drought periods; and decades, as atmospheric CO₂ increases.

A major goal is to interact with federal, state, and local government agencies as well as non-governmental organizations to provide information useful for management decisions regarding land-surface vulnerability to wind erosion. Another goal is to provide to managers and other parties ongoing remote sensing and meteorological monitoring bearing on the vulnerability of the land to natural and human disturbances.

Specific goals for Canyonlands work

- Understand geologic origins of soil nutrients and the interactions of soil compounds and plants.
- Understand geomorphic controls on plant distribution
- Understand the recent (past several decades, centuries, millennia) geologic/geomorphic evolution of the ecosystem to reveal patterns of surface stability and instability.
- Recognize areas vulnerable to wind erosion and soil loss.
- Understand conditions of cheatgrass (and other exotic plants) invasion to predict areas most vulnerable to expansion and to help devise mitigation strategies.

Findings/Accomplishments for 2009: This is a long-term project, with which we hope to understand climatic variability and its effects on dust projection and soil fertility. Multiple years will be required to capture the full range of variability so that we may better understand the role of extreme events, as well as normal regimes.

17) Study Title: Study and Documentation of Cactaceae, Agavaceae, and *Cirsium* within Canyonlands National Park

Permit No.: CANY-2010-SCI-0017

Principal Investigator: Wendy Hodgson

Purpose of Scientific Study: The goal of this research proposal is to better understand certain genera within the Cactaceae and Agavaceae, namely, *Opuntia*, *Cylindropuntia*, *Sclerocactus*, *Echinocereus*, and *Yucca*, in addition to certain species of *Cirsium* through observation and documentation of their populations with herbarium specimens, photographs and extensive data. These genera are characteristically poorly documented with adequate material and data on herbarium specimens, if they are made at all. The lack of quality specimens has hindered systematic research; it is no coincidence that their affinities, origins and species delineations are not understood and confusing.

Findings/Accomplishments for 2009: Canyonlands National Park (and surrounding areas, at least to south) continues to be problematic with regards to

Agavaceae and Cactaceae. Despite this, we now have a better understanding of what might be going on with these populations, although new questions have arisen. The area surveyed and whose populations were documented is from the south end of the park's border to Peekaboo Spring, ca. 26 miles north. Three collection trips were made. A trip in April allowed for initial survey of the populations, collection of plants in early flower, and flower buds for possible cytological analysis. June's trip was perfect to document the *O. cf. phaeacantha* populations in full flower, but too late for most *O. polyacantha*; it was the tail end for *O. fragilis* flowering. October's trip allowed us to document plants of all of the above with fruits. Populations, at least in this 26-mile linear area, appear to be a very large hybrid swarm, involving *O. phaeacantha*, *O. fragilis* and *O. polyacantha*. It is possible that *O. macrorhiza* may have had some influence in the past, although no plant was found representing this species. Unusual forms of what appears to be *O. polyacantha* with introgression from *O. phaeacantha* is found, having the characteristic pads and spine clusters of the former but flowers of the latter (large, petals yellow with conspicuous red-maroon bases). I have never seen this form elsewhere. Although there remain many questions, these collections, with photos (as well as seeing populations in the field) have helped us greatly in preparing the treatment of *Opuntia* for the Intermountain Flora. Further work is required, and it is hoped that we can continue, with a shift towards the central and northern part of the Park in the near future.

The Colorado Plateau dry-fruited yuccas (section *Chaenocarpa*) continue to be problematic. The common species within Canyonlands National Park is *Y. angustissima*; as to what variety they are is not determined as yet, if one recognizes the species' four varieties (Reveal 1977; Hess and Robbins 2002) treatments recognizing four varieties is valid. It is possible that such varietal distinctions are warranted; I do not know as yet; further studies are needed. Such studies require seeing more of the populations in the field, better documentation - with photographs - key character descriptions, and material for molecular analysis, all of which we have initiated in our 2009 field work. An exciting find was an actual population (small as it is) of the putative hybrid involving the capsular-fruited *Y. angustissima* and the fleshy-fruited *Y. baccata*. Although hybridization (in more closely related taxa) has been proposed (McKelvey 1943, Webber 1953), it has generally not been seriously considered, pending further study (Reveal 1977; Hess and Robbins 2002). In *Flora of North America*, Hess and Robbins (2002: 428) "are somewhat skeptical of the potential for crosses between baccate species (*Y. baccata* and *Y. madrense*) and capsular species (*Y. elata*)."

16) Study Title: Evidence of impact structure at Upheaval Dome from fission-track thermochronology

Permit No.: CANY-2009-SCI-0016

Principal Investigator: Phil Armstrong

Purpose of Scientific Study: Upheaval Dome's origin has been debated for almost a century. The main hypotheses include (1) formation due to the upward passage of a salt dome and (2) an impact origin. Both of these hypotheses have been challenged--namely the salt dome origin has been challenged because there is no evidence of salt having moved through the core of the dome structure and there are no fragments of salt formations (like the Paradox Formation) in the salt passage area. The impact hypothesis has gained much attention because of the shape and structural deformation of the area are consistent with an impact structure. Numerical modeling of an impact also agree nicely with an impact origin. However, until recently, very few if any critical indicators of shock due to an impact have been

positively identified. These include shock metamorphic structures in sand (quartz) grains found within and adjacent to the impact location. Recently, Buchner and Kenkmann (2008) reported unambiguous evidence of impact in a paper entitled "Upheaval Dome, Utah, USA: Impact origin confirmed" in the journal *Geology*. They identified shocked quartz in many samples of sandstone from the Jurassic Kayenta Formation collected from sites approximately 1.5 km NE of the dome central uplift. Now that the impact structure origin has essentially been confirmed with microscopic shocked quartz identification, the goals of our proposed project are to (1) attempt to develop other techniques as described below based on Upheaval Dome samples that can be used to confirm other impact structures where shocked quartz may not be identified and (2) constrain the age of the impact at Upheaval Dome using fission-track dating techniques. Samples will be processed to expose naturally occurring fission tracks, which form from the spontaneous fission of uranium-238 in minerals. These tracks are typically about 15 - 16 microns long and form randomly oriented straight damage zones in the crystals. Two aspects of the fission tracks make them potentially attractive identifying impact structures. First, during impact the temperatures are so great around the impact region that fission tracks (especially in apatite) may get completely annealed (shortened). This shortening essentially restarts the clock for formation of the tracks and then the numbers of tracks can be used to date the timing of impact. Second, because the tracks are initially straight and randomly oriented, any strain imparted at impact (which deforms other crystals such as quartz) should also deform the fission tracks. Thus, deformed (bent and warped) fission tracks near the impact may indicate an impact origin.

Reference cited:

Buchner, E. and Kenkmann, T., 2008, Upheaval Dome, Utah, USA: Impact origin confirmed, *Geology*, v. 36, p 227-230.

Findings/Accomplishments for 2009: Two samples were collected on 3/30/09 from the Kayenta Sandstone at Upheaval Dome in Canyonlands NP. Sample AW09-1 was collected from the inner dome area as close as possible to where Buchner and Kenkmann (2008) found shocked quartz. We collected sandstone that is coarse grained and relatively immature to increase the likelihood of finding the mineral apatite for proposed fission-track studies. The second sample (AW09-2) was collected outside the main dome area where Shafer Trail intersects Highway near the Visitor Center. These two samples were chosen to give comparisons of apatite crystals with potentially annealed and deformed fission tracks for AW09-1 with apatites from sample AW09-2 outside the dome area that should not have been affected by impact. To date, these samples have been processed to extract the mineral apatite. In both samples, sufficient apatite was found for analysis. Apatites from both samples have been mounted in epoxy and ground/polished to expose internal mineral features. We are just beginning to analyze the fission track numbers, densities, and fission-track features, but have no results to date. Additionally, one aliquot from each sample is being specially prepared for irradiation at the Oregon State University TRIGA reactor. These samples will be used for determining a fission-track age after irradiation and sufficient post-irradiation equilibration.

18) Study Title: Reconstructing the geometry and palaeoclimate of the Cedar Mesa and White Rim Sandstone (Permian)

Permit No.: CANY-2009-SCI-0018

Principal Investigator: Nigel Mountney

Purpose of Scientific Study: This field-based research project aims to examine and document the sedimentology and paleoenvironment of a succession of Permian-age, arid-climate continental successions exposed within the Paradox Basin

of the Canyonlands District, SE Utah. Field-based data are being used to develop and constrain quantitative predictive models for fluvial and eolian desert-margin evolution within ancient arid sedimentary systems. This is being achieved through an ongoing outcrop study of mixed fluvial, eolian and lacustrine strata within the Permian Cedar Mesa Sandstone and Elephant Canyon Formations (Lower Cutler Beds). The project is helping to determine the response of desert margin deposits to cyclical changes in climate.

Findings/Accomplishments for 2009: Research conducted for the 2009 reporting year has focused on characterising the stratigraphy and architecture of deposits of both the lower Cutler beds (formerly the Elephant Canyon Formation) in the area around Indian Creek and also the undivided part of the Cutler Group in the Shafer Basin area to the north and east of Canyonlands NP. For the lower Cutler beds study, data have been collected in the form of sedimentary logs, architectural panels and photomontages. These have been used to trace key stratal surfaces over regional distances and to relate individual facies types to the architectural elements present within the succession. A series of incised valleys and their infills have been mapped out and these have been related to mixed fluvial, eolian and shallow marine facies associations. A series of depositional models have been devised to account for the evolution of the system in relation to relative sea-level change and to associated changes in climate. This work is now yielding important results. A paper is currently in press in the journal *Sedimentology* (the leading international publication in the field) and a further paper is in preparation for the journal *Basin Research*.

The work on the undivided part of the Cutler Group utilised sedimentary logging and architectural panel analysis to erect a regional stratigraphic framework for a part of the Permian Cutler Group succession that has hitherto received only scant attention from geologists and which remains rather poorly understood. This work will continue outside the boundary of the Park in 2010. Other publications relating to previous work undertaken as part of this project have been published or have gone into press in the 2009 year.

Cain, S.A. and Mountney, N.P., 2010. Downstream changes and associated fluvial-aeolian interactions in an ancient terminal fluvial fan system: the Permian Organ Rock Formation, SE Utah. In: Davidson, S, Leleu, S. and North, C. (eds), *From River to Rock Record*, SEPM Special Publication, in press.

Jordan, O.D. and Mountney, N.P., 2010. Styles of interaction between aeolian, fluvial and shallow marine environments in the Pennsylvanian-Permian Lower Cutler Beds, southeast Utah, USA. *Sedimentology*, in press.

Cain, S.A. and Mountney, N.P., 2009. Spatial and temporal evolution of a terminal fluvial fan system: the Permian Organ Rock Formation, South East Utah, USA. *Sedimentology*, 56, 1774-1800.

19) Study Title: Annual Forest Land Inventory of Utah

Permit No.: CANY-2009-SCI-0019

Principal Investigator: Renee O'Brien

Purpose of Scientific Study: The Interior West Forest Inventory and Analysis program is responsible for statewide inventories in eight states. The purpose of this ongoing inventory is to gather information on condition and trends of forest resources to assess plant diversity; fuels and potential fire hazards; condition of wildlife habitats; mortality and risk associated with fire, insects, or disease; and biomass, carbon storage, forest health and other general characteristics of forest ecosystems. Under the annualized inventory system, each field plot is visited one every 10 years, with approximately 10 percent of the total plots visited each year within a state. The FIA program produces a five-year report for each State.

Findings/Accomplishments for 2009: As part of the Annual Forest Land Inventory of Utah, field crews visited three plots at Canyonlands National Park during the 2009 field season. Two of these plots did not meet the inventory's definition of forest land, so no further data were recorded. A third plot was deemed to be too hazardous for the field crew to safely access. The results of this ongoing inventory are periodically updated and made available at www.fs.fed.us/rm/ogden/publications/. The five-year report for the Utah inventory will be released in Spring 2010.

21) Study Title: Collection of Younger Dryas Black Mat Materials from the Maze District, Canyonlands National Park, Utah and Analysis for Impact-Related Nanodiamonds and Magnetic Microspherules Using Scanning and Transmission Electron Microscopy

Permit No.: CANY-2009-SCI-0021

Principal Investigator: Pete Poston

Purpose of Scientific Study: A controversial new theory has recently emerged in Archaeology that claims a comet impact 12,900 years ago (12.9-ka) was responsible for the extinction of Pleistocene megafauna, initiated the end of the Clovis Period of habitation, and triggered the succeeding Younger Dryas climatic cooling event (1). It is the purpose of this research project to collect a Younger Dryas black mat sample that has been identified by Ranger Gary Cox as being present in Horseshoe Canyon, the Maze District of Canyonlands National Park, UT. Once collected, the materials would be analyzed to verify the presence of impact-related nanodiamonds and magnetic microspherules using Scanning Electron Microscopy (SEM) and Transmission Electron Microscopy (TEM). The Principle Investigator (PI) already has a budget for the project (\$4375), two interested students and available facilities located at Oregon State University, about twenty miles south of the PI's home institution.

Findings/Accomplishments for 2009: A. SEM-EDX Results on Iridium-Enriched Magnetic Microspherules Scanning Electron Microscopy (SEM) in conjunction with Energy Dispersive X-ray fluorescence (EDX) is the method of choice for the detection of Iridium-enriched magnetic microspherules. This grant provided funds to purchase beam-time at the Electron Microscopy Facility at Oregon State University.

The first stage of the analysis involves separation of the microspherules from the organic layer. This is easily accomplished by using a powerful Neodymium magnet. Student help was used to carry out the extraction procedure, also funded by this grant. Once the magnetic fraction was separated, individual rounded microspherules were manually selected under a low-power dissection microscope. The microspherules were then attached to an SEM "stub" covered with an adhesive, and the SEM data obtained. Once the microspherule is imaged within the field of view of the SEM, it is then analyzed with the EDX. The results suggest the presence of Iridium, but the low percentage of Iron and Titanium is at odds with the results published in the literature. Nevertheless, it is an encouraging result and further refinement of the entire process from extraction to analysis will be undertaken.

B. TEM Results: Nanodiamonds Transmission Electron Microscopy (TEM) is used for the detection of impact-related nanodiamonds. Once a possible cluster of nanodiamonds are located through a manual search, the electron beam is focused onto the possible nanodiamonds, producing a characteristic diffraction pattern. This diffraction pattern is unique to the exclusion of all other varieties of terrestrial nanodiamonds. The extraction of the carbonaceous component of the black mat is simply carried out by water flotation. Once again, the result is manually separated under a dissection microscope, and the particles are mounted on a standard TEM grid. The results of this procedure were compared to impact-related nanodiamonds

conclusively identified in the literature. Possible nanodiamonds magnified under the TEM show similarity to those given in the literature. The resulting electron beam diffraction patterns were also compared to the literature. According to the prominent researcher in this area, Dr. Allen West of GeoScience Consulting, Tucson Arizona, these patterns look more like graphite than nanodiamonds. But he was very encouraging that nanodiamonds were detected. He has made some useful suggestions summarized in the next section, "Future Directions".

C. Future Directions: In order to obtain a better signal for the nanodiamonds, the carbon microspherules need to be crushed with a rounded and fire polished glass rod for 3-4 minutes. The crushed fraction is then suspended in alcohol or ammonia, and added to a TEM grid. The nanodiamonds tend to be found in groups or clusters, which aids searching for them under a typical TEM magnification of 50K. The magnetic microspherules simply need further time and effort to isolate and analyze the extract. Magnetic microspherules are exceedingly rare, sometimes numbering as little as 1 per 150 grams of material as reported in the literature.

22) Study Title: Colorado River Tamarisk Biological Control Monitoring Project: Loma, Colorado to Lake Powell

Permit No.: CANY-2009-SCI-0022

Principal Investigator: Lindsay Clark Tate

Purpose of Scientific Study: The purpose of this study is to support a body of knowledge to determine the value of the tamarisk leaf beetle, *Diorhabda elongata*, as a tamarisk biocontrol agent, on the Colorado River from Loma, CO to Lake Powell, UT. The four goals of this study are to obtain data concerning the dispersal and establishment of *D. elongata*, measure the efficacy of the beetle in controlling tamarisk, monitor the safety of biological control, and to ascertain the impact of biocontrol on riparian ecology.

The overall impact of *D. elongata* on western ecology is not well understood. Preliminary studies show that local birds and generalist arthropods gain a significant food source with the introduction of the beetle (Dudley and DeLoach 2004, DeLoach et al. 2004, Herrera et al. 2001). This is beneficial for tamarisk ecosystems as they support less arthropod abundance than native vegetation (Stevens 1985, Shafroth et al. 2004). Defoliation by *D. elongata* also immediately reduces the amount of water tamarisk is able to transpire (Pattison et al. 2006), increases branch mortality, decreases flower and seed production, and in some situations causes plant mortality (Kazmer et al. 2006). Among factors most critical to tamarisk biocontrol success is the ability to predict and control beetle dispersal and establishment. Tamarisk mortality in cage tests was achieved following three sequential seasons of defoliation. Initial field studies indicate that more seasons of defoliation may be required to achieve tamarisk die off. In some instances beetles avoided plants that had been defoliated the year before, affording the tamarisk a recovery period and decreasing chances for mortality (Dudley and DeLoach 2004). Thus, ensuring beetle population longevity in any one area is essential to successful tamarisk control. Data collection will provide information to support the three major long-term research objectives shown below with their correlating short-term objectives:

- (1) To obtain data that will aid in the future prediction and control of *D. elongata* dispersal and establishment. Gathering such data is invaluable to predict patterns and rates of eventual tamarisk mortality rates. Thus, the first immediate objective is to: (a) track largescale dispersal patterns of *D. elongata*.
- (2) To measure the efficacy of *D. elongata*, in the control of tamarisk. Efficacy data will provide critical information to biocontrol viability. Therefore, the second

immediate objective is to: (b) measure tree stress by recording changes in tree morphology (i.e. defoliation).

(3) To ascertain the safety of *D. elongata* as a biological control agent. The possibility of biocontrol agents switching hosts is a concern. Although there are no recorded host-plant switches in weed biocontrol it is prudent to note any feeding, damage, beetle development, or population suppression of non target plant populations. For this reason one objective will be to: (c) routinely survey non target plants for the presence of *D. elongata*. Beetles have been found on other plants but in no instance have they persisted or impacted plants other than tamarisk.

(4) To study the impact of *D. elongata* on riparian ecology. To date data shows an increase in other non-native plants (kochia, Russian knapweed and perennial pepperweed) in tamarisk defoliation areas. This information was gathered at sites (Lovelock, NV and Pueblo, CO) with little opportunity for other vegetation to establish. Thus, another objective is to: (d) collect a larger database of vegetative response to tamarisk defoliation. These objectives represent research needs identified by several consortia of scientists and practitioners such as the Saltcedar Biological Control Consortium of Texas, New Mexico, and Mexico and participants in the Tamarisk Research Conference held in Ft. Collins, CO in October of 2006. The results of these western Colorado research objectives will inform ongoing research analyzing *D. elongata*.

Findings/Accomplishments for 2009: Surveys occurred: 5/10/09-5/15/09 Colorado River, 9/5/09-9/11/09 Colorado River, 9/4/09-9/7/09 Green River
Along the Colorado River in May beetles were found in small aggregations scattered from Potash downstream for 26 km. There surrounding the mouth of Monument Creek densities rose and consistent aggregations were recorded for the next 27 km, past the confluence of the Green. At Rapid 1 surveys ceased and did not resume until Clearwater Canyon. From Clearwater downstream to Hite, no beetles were recorded. No larvae or defoliation was discovered in May. In September surveys found beetles along the Colorado River all the way to Hite Marina. From Potash downstream small aggregations were found until 48 km downstream where densities rose 4 km downstream of Monument Creek. Consistent high densities were recorded for 40 km from there on, continuing until 19 km below the confluence of the Green River. No beetles were located for the next 20 km until Clearwater Canyon. From Clearwater small-medium sized aggregations were recorded for the next 40 km to Hite. Defoliation along the Colorado River witnessed in September had a strong correlation to beetle distribution. This was apparent from Potash downstream where high level defoliation was recorded for 16 km. There it transitioned into medium level intensity staying constant across the next 23 km until Lathrop Canyon. From Lathrop downstream patches of mostly low level defoliation were found infrequently over another 23 km until intensities rose again to medium levels which continued over the next 20 km until Spanish Bottom. Where at the end of Spanish Bottom high level defoliation extended downstream for 11 km. In unison with the distribution of beetles defoliation disappeared near Mile Long Rapid for 11 km. Finally at Gypsum Canyon infrequent low-medium level defoliation was observed for 19 km. At the mouth of Cove Canyon defoliation transitioned into high level defoliation spread over a further 10 km transitioning at Freddie's Cistern to infrequent patches of low, medium, and high level defoliation continuing down to Hite Marina.

Along the Green River in September, 2009 tamarisk leaf beetle densities were found widely scattered in small-medium sized aggregations across the river from Mineral Bottom Boat Ramp down to the Colorado River confluence. Only 23 out of the 49 areas sampled (47%) had a recorded beetle presence, with an average of 3.18 beetles caught per sample point. No beetles were located for 15 km from Millard

Canyon to Tuxedo Bottom near the Turks Head. Respectively, defoliation in September also displayed a scattered distribution with only two small patches of high/medium level defoliation located from Mineral Bottom downstream for ~30 km where in unison with beetle distribution high level defoliation was recorded from Millard Canyon downstream to the Sphinx (5 km above Tuxedo Bottom). Medium-low level defoliation continued from there downstream 7 km to Soda Spring Canyon. No defoliation was recorded at that point for another 9 km until low level defoliation began to spread out over the riverside tamarisk for 13 km ending just below Jasper Canyon. Very little defoliation was recorded for the next 14 km, until 2 km above the confluence of the Colorado and Green Rivers, medium level defoliation was found spreading upstream extending from the confluence.

Along both the Colorado and Green Rivers coyote willow (*Salix exigua*) was found to be the predominant secondary species alongside tamarisk, found present at 70% of sites surveyed along the Green River. Similarly, 82% of the points surveyed along the Colorado from Potash to Spanish Bottom had willows present. Comparatively only 9% of points had willows present below Spanish Bottom, with the predominant secondary species being Russian thistle (*Salsola tragus*) at 48% of the points surveyed.

During the surveys tamarisk leaf beetles were not recorded feeding upon any plant species but tamarisk.

23) Study Title: Upheaval Dome: Evidence for Meteorite Impact

Permit No.: CANY-2009-SCI-23

Principal Investigator: Rachel Daly

Purpose of Scientific Study: Upheaval Dome is a ~5.5 km wide circular topographic depression in Canyonlands National Park, Utah. Upturned beds around the feature indicate a structural dome located above salt layers in the Pennsylvanian aged Paradox Formation. Its ambiguous origin, either as a salt diapir or a meteorite impact, has been debated for the last 75 years. Recently, planar deformation features (PDFs) were discovered at the dome (Bucher and Kenkmann, 2008). Based on current field work we propose two methods of deformation present at the dome: meteorite impact and subsequent salt diapirism. Based on field and aerial photograph analysis, we have identified and characterized both dynamic and slowly-formed deformation features around the dome. Clastic dikes are representative of the dynamic injection of fluidized material into the surrounding rock, and fractures with dendritic branching patterns may represent dynamic fracturing; however, multiple sets of regular, planar fractures (joints and deformation bands) are common around the dome and point to a slow growth process. We hypothesize that although the discovery of PDFs may seem to be the end of the argument concerning the origins of the dome, post-impact and potentially longlived salt flow beneath the crater may still have had an effect on the formation of the feature.

Findings/Accomplishments for 2009: Field work has focused on observing brittle deformation in and around the ring syncline. This area is pervasively deformed, and as such affords many varied examples of brittle failure. This work complements the extensive research done in the central uplift of the dome (Kenkmann et al, 2005). Many different fracture types are present, such as joints, deformation bands, and shear fractures. There is also variation within each type. Many shear fractures are planar and regularly spaced; however, there are also many sets with a distinct curvilinear shape, the orientation of which varies between each individual fracture. Likewise there are many planar deformation bands, but also many with anastomosing morphologies and distinct truncations suggesting concurrent growth. The multiple morphologies present at the dome suggest different mechanisms of

formation, which may indicate a dynamic impact event followed by a slowly evolving salt diapir.

Data collection sites were spatially georeferenced in ArcGIS. To determine whether such fractures are related to dome formation or are products of a regional stress field, we isolated local from regional deformation by removing three regional fracture sets from the overall dataset. Remaining fracture orientations in tilted beds were then back-rotated to determine original formation orientations. We do see fractures radial and circumferential to the dome, as would be expected for a meteorite impact or with the intrusion of a cylindrical body, somewhat analogous to a salt diapir.

We categorize the different fracture morphologies observed at the field site as either dynamic or slowly-formed through progressive shearing. Clastic dikes, previously documented at the dome (Huntoon, 2000; Kenkmann 2003), are features formed by the dynamic injection of fluidized material into rock. Fractures formed by ongoing shearing may have been formed by the movement of salt in the Paradox Formation after meteorite impact. Thin section analysis of these fractures will provide key information about their mode of formation.

Preliminary petrographic results show evidence of grain size reduction and change in rounding and aspect ratio in shear zones. Also present at the grain-size scale are fractures within single grains, undulatory extinction, fluid inclusions and planar lamellae. Field observations lead us to conclude that both dynamically and slowly formed features are present at Upheaval Dome, supporting the hypothesis that subsequent salt movement added to the deformation caused by meteorite impact. However, many questions remain to be answered.

There is very strong evidence that a meteorite impact occurred at Upheaval Dome; however, the dynamics of salt flow and the differences in overburden created by an excavated crater would promote movement of salt in the Paradox (Shultz-Ela et al, 1993). The lack of salt present at the surface of the dome does not rule out deformation of the Paradox Formation in the subsurface. This study underscores the importance of distinguishing between deformation at an impact site that was formed by the meteorite impact itself, and deformation formed post impact by other processes. In this case there may be a history of salt flow that, without careful observation, is obscured by the effects of the impact event.

24) Study Title: Linking whole-system carbon cycling with quantitative food webs in the Colorado River.

Permit No.: CANY-2009-SCI-0024

Principal Investigator: Theodore Kennedy

Purpose of Scientific Study: The Colorado River below Glen Canyon dam has been dramatically altered by modifications of flow, temperature, sediment, and nonnative species that have severely reduced native fish populations. For the past 3 years we have been estimating the relative importance of the various food resources to fishes in this system to establish the degree to which native fishes are limited by food resources, by either low production at the base of the food web or via shunting of carbon to exotic animals such as nonnative rainbow trout and New Zealand mudsnails. Our research below Glen Canyon dam shows high rates of primary production immediately below the dam and decreasing downstream as turbidity increases. Insect production follows this pattern in primary production and is in part derived from algal production. Other investigations have documented alterations in the fish assemblage due to Glen Canyon Dam, but, because of the paucity of data on invertebrate taxa present prior to Glen Canyon Dam and in upstream reaches, we do not know the degree to which the amount of production differs from historic conditions. Moreover, because of lack of data on tributary-derived carbon inputs

or rates of primary production prior to dam construction, we do not know the extent to which construction of Glen Canyon Dam has influenced productivity in the Colorado River ecosystem. Cataract Canyon is relatively unimpacted by river regulation and dams and therefore could serve as a "reference site". We propose using the same sampling methods and techniques that we have employed over the past 3 years to estimate food production in Grand Canyon to estimate food production and trophic linkages in Cataract Canyon during summer 2009. These data will allow us to estimate the dominant food sources for native fishes in an unimpacted segment of the Colorado River and provide some context for the heavily impacted segment of the Colorado River in Grand Canyon that we have studied for the past 3 years.

Findings/Accomplishments for 2009: No activity was conducted this report year.

25) Study Title: Assessment of Stocked Razorback Sucker Reproduction in the Lower Green River via Larvae and Young of Year Collections.

Permit No.: CANY-2009-SCI-0025

Principal Investigator: Paul Badame

Purpose of Scientific Study: This project targeted determining and monitoring early life stages of endangered fish in the Colorado River drainage, specifically the Colorado pikeminnow (*Ptychocheilus lucius*) and the razorback sucker (*Xyrauchen texanus*). Monitoring of young-of-the-year (YOY) Colorado pikeminnow was initiated in 1986 within the upper Colorado River basin as part of the Interagency Standardized Monitoring Protocol (ISMP). The ISMP sampling in the lower Green and Colorado Rivers was proposed to monitor recruitment success of first year endangered fishes, to correlate cohort strength and condition to abiotic and biotic parameters, and to provide data for a predictive model measuring future cohort strength. Since its inception, the ISMP protocol has been updated to refine its scope and methods to focus not only on pikeminnow but all small-bodied fishes allowing for assessment of other projects such as nonnative control actions.

A comprehensive synthesis of the effect of changes in physical habitat (as a function of flow and flow variability) and other environmental conditions on the small-bodied fish community (emphasis on Colorado pikeminnow) is underway. Another aspect of this project is designed as a pilot study to determine the presence/absence of early life stages of endangered razorback sucker in lower Green River. By the mid 1990s most wild riverine adult razorbacks in the Green River basin were limited to one population in the middle Green River with an estimated size of about 500 adults (Modde et al. 1996). Although sampling from 1992-96 did verify the presence of larval razorback in both the middle and lower Green River it was believed that mortality rates on those larvae were very high and did not provide any significant recruitment into the wild population (Muth et al. 1998). Habitats were identified for razorback sucker larvae as ephemeral shoreline, ponded lower portions of flooded tributary streams, side canyons, washes, canals, and channels (Muth et al. 2000). Historic collections sites for larvae were Millard Canyon, the confluence of the San Rafael River, and Green River Valley area. By 2000, wild adult razorback suckers in the Green River Basin were very rare and the few remaining have likely perished (Bestgen et al. 2002). Stocking of hatchery reared razorback sucker in the Green River basin began in 1999 as a means to augment the population and continues through this current time (US Fish and Wildlife Service 2002). Thus, all current reproduction observed is likely by stocked adults. Determining the reproductive success of stocked fish in the Green River is key to understanding their ability to maintain a viable self sustaining population. During sampling for adult

Colorado pikeminnow (2001-2003 and 2006-2008; UDWR unpublished data), within the lower Green River, the occurrence of adult razorback captures had increased greatly from 9-10 individuals per year to an average of 320 captures between 2006 and 2008. In addition, during the 2007-08 adult pikeminnow sampling an increased number of ripe adult razorbacks have been captured throughout the lower Green River and in two specific locations congregations of ripe razorbacks displaying spawning behavior have been observed and captured. In 2008, three age 1+ razorbacks were captured within the lower Green as well. This progression of events over the last three years strongly suggests that adult stocked razorback are now persisting in large enough numbers within the lower Green to facilitate successful spawning. Successful spawning among stocked razorback is an important component of a viable recovery for the species. Determining the timing, locations, and relative extent of larval recruitment will help define the success of the species. Sampling focused on year one survival of larvae will provide information about potential road blocks to recruitment of young suckers into the adult population.

Findings/Accomplishments for 2009: According to ISMP protocols, two backwater habitats within every 5-mile sub-reach, as available, were seine-netted to sample larval fish occupying this habitat. The annual monitoring trip for young-of-the-year (YOY) Colorado pikeminnow in the lower Green and Colorado Rivers was September 13-18, 2009. For both the lower Green and Colorado Rivers, a total of 666 YOY Colorado pike minnow were captured and measured (423 for the lower Green River, 243 for the lower Colorado River). This exceeds the 10-year averages for catch rates on both rivers. The lower Colorado River catch rates were higher than the 15-year average. Nonnative species, such as red shiner (n=5,890 for both rivers), fathead minnow (n=1,304 for both rivers) and gizzard shad (n=58 for both rivers) continue to dominate the samples. Sampling for larval stages of razorback sucker consisted of light trapping in habitats conducive to early stage development. Light traps were set between June 10 and June 26, 2009 at the San Rafael River confluence and Millard Canyon sites. A total of 21 samples were collected in the lower sites. In addition to light trapping, 1 m wide larval kick seines were used to sample 116.6 m² between May 21 and June 26. A total of 57 larval light trap samples were collected (including sites in Green River Valley and San Rafael River confluence) and 49 of those were sent to the Colorado State University (CSU) Larval Fish Laboratory (LFL) for identification (Project #15). In addition, 38 samples were collected via larval kick seine and 18 of those were sent to CSU LFL and findings are still pending. Samples will be destroyed during analysis. In late July and mid August, two seining trips were completed sampling available YOY habitat between Green River (RM 120) and the confluence of with the Colorado River (RM 0). Main channel water temperatures varied between 25-28°C and backwater habitats ranged from 26-32°C. A total of 3,640 m² were seined during the trips collecting 78 YOY samples of which 17 were sent to CSU LFL for ID. Results are pending and samples will be destroyed during analysis.

26) Study Title: Determinants of geographic distribution in western North American monkeyflowers

Permit No.: CANY-2009-SCI-0026

Principal Investigator: Seema Sheth

Purpose of Scientific Study: The goal of this research is to evaluate the roles of evolutionary and historical processes in shaping the geographic distributions of species. To do so, we are focusing on species of monkeyflowers that occur in western North America. Specifically, we are addressing two main objectives: 1) Limits to niche evolution: Evaluate whether adaptive genetic variation and response to selection are lower in marginal populations than in central populations within species,

and lower in species with narrow niches than in species with broad niches; 2) History: Assess the relative roles of the vicariance and long-distance dispersal hypotheses in explaining geographic patterns of speciation. To determine whether reduced evolutionary potential at species' range margins limits species' responses to natural selection, our aim is to collect seed from *Mimulus eastwoodiae* populations and conduct artificial experiments to compare quantitative genetic variation between central and marginal populations within its range. To determine whether rare species are products of historical events, our goal is to collect leaf tissue from populations across the geographic range of *Mimulus eastwoodiae* to infer historical demography from patterns of genetic variation.

Findings/Accomplishments for 2009: We visited one population of *Mimulus eastwoodiae* in an alcove adjacent to the Neck Spring Trail. We collected one fruit from each of five individuals in the population, and leaf tissue samples from each of 17 individuals in the population. To establish growth protocols in a common garden, we planted one fruit in the Colorado State University Greenhouse, but the fruit capsule appeared empty and there was no germination. We have not yet extracted DNA from leaf tissue samples. We may do additional collecting of *Mimulus eastwoodiae* fruits in Canyonlands National Park in summers 2010 and/or 2011.

27) Study Title: Investigations into *Cucurbita foetidissima* in Canyonlands National Park.

Permit No.: CANY-2010-SCI-0027

Principal Investigator: Wendy Hodgson

Purpose of Scientific Study: *Cucurbita foetidissima* is a wide-ranging species of the Southwest to Missouri and Texas. In Utah it is limited to two populations, having been once found within Glen Canyon near the San Juan - Kane county line. One of the two remnant populations is in Salt Canyon, below Jump Up spring at an impressive archaeological site supporting numerous granaries. *Cucurbita foetidissima* has a long history of multiple uses by indigenous cultures and shows potential as an arid region crop. The seeds of *C. foetidissima* were used for food by many groups, the oil generally edible having 25-45% content; seeds of *foetidissima* contain 22-35% protein, comparable to legumes. Roots and fruits are well known for medicinal and cleansing properties, and there are references to them being used for food (despite containing cucurbitacin, a triterpenoid glycoside). According to Cutler and Whitaker (1961:470-471): "The wild species with the widest distribution and the one most frequently seen in collection from living Indians or from archaeological sites is *Cucurbita foetidissima*." All parts of the plant were used, with some form of treatment required, and it appears to have been an important multiuse plant. It was suggested that selection for the oily seeds may have preceded selection for the sweet flesh of melons (Rea 1997). Oils are highly unsaturated in these more xerophytic gourds (compared to mesic-adapted domesticated and wild species). Breeding programs to develop hybrids having seed oil higher in polyunsaturates is feasible. There was identified potential for developing *C. foetidissima* as a starchy root crop with superior properties compared to tapioca and other commercially available starches, but to do so requires extraction of its bitter principles. *C. foetidissima* is a very productive, high-yielding plant as well with regards to seeds. There are many native species that were probably used for a number of purposes and that were involved at different levels in the agricultural landscape - *Cucurbita foetidissima* is probably one of them. We would like to voucher with 2 herbarium specimens the leaves, flowers and fruit. We would also like to take a small fragment of the leaf from 3 plants to use for molecular work. Comparisons can be made with other populations of *C. foetidissima* to see if there are differences and evidence for selection or hybridization with

cultivated gourds. There are many primers for different regions of different species of *Cucurbita* available for comparison. This population has not been sampled.

Findings/Accomplishments for 2009: Two trips were conducted in June and October to document the known cucurbit, identified as *Cucurbita foetidissima*, in flower (June) and fruit (October). Sites the species was documented from include Gourd Grotto and another site ca 1/3+ mile north of this (herbarium specimens, photos and notes). Attempts to find another gourd site just south of All American Man was futile, the plant perhaps washed away as it was described as occurring at the edge of a drainage. Seed was collected and will provide material for not only the herbarium voucher, but for oil content and molecular study as well, to determine if there might be any difference between these populations and those south of these sites that are presumed growing wild.

28) Study Title: Chronostratigraphy of alluvium in Horseshoe Canyon and indirect dating of Barrier Canyon rock art: Phase II

Permit No.: CANY-2009-SCI-0028

Principal Investigator: Joel Pederson

Purpose of Scientific Study: The phase II proposed research has the goal of focusing in on sampling and work at the Great Gallery panel of Barrier Canyon-style rock art. Through dating of sediment laterally adjacent to the panel, a more precise maximum age constraint can be obtained. Also, by dating of rockfall boulders fallen below the rock art panel, both a minimum age for the art and possibly a direct age of the art may be obtained from the shielded rock surfaces of the talus.

Findings/Accomplishments for 2009: In March of 2009, a report of the results of phase I research was provided to CNP. Subsequently, a proposal for a second phase of research was submitted in June of 2009, and a research and collecting permit was granted for work to begin in August 2009. One sampling trip was successfully conducted on August 10, 2009 with the help of CNP ranger Gary Cox. On that trip, we recorded the sediments and collected a suite of samples from the deposit laterally adjacent to the Great Gallery panel. The second sampling trip proposed for phase II research has not yet been conducted. It was originally planned for later in the fall of 2009. But logistical difficulties, specifically in exactly how to sample the talus boulders, has delayed this sampling until sometime in spring of 2010.

Also in the fall of 2009, final reduction and partial-bleaching analyses of the main phase I OSL samples were completed. These fully analyzed results revealed that ages are significantly younger than had been preliminarily reported in the March 2009 report to NPS, revising somewhat the chronostratigraphy we've established for Horseshoe Canyon.

29) Study Title: Population monitoring of humpback and bonytail chub in Cataract Canyon

Permit No.: CANY-2009-SCI-0029

Principal Investigator: Paul Badame

Purpose of Scientific Study: Goals: Maintenance of long term catch rate trend data, longitudinal distributions, and population size structures for humpback and bonytail within Cataract Canyon.

Objectives:

1. Complete one ten-day pass each year sampling five sites within Cataract Canyon.
2. Obtain highest possible rates of capture of humpback and bonytail within concentration habitats and maximize number of individuals marked and captured at each sampling site.
3. Determine annual catch rate trend for chubs, examine population size structure, and compare longitudinal distribution to past years.

Findings/Accomplishments for 2009: One nine-day sampling trip was completed between September 23 and October 1, 2009. Total sampling effort included 623 hours of trammel netting and 5.5 hours of electrofishing. Total captures for endangered fish included 20 adult humpback chub and 6 juveniles (2 identified as *Gila* spp.). Three of these humpback chubs were recaptures, having been marked in previous years. One bonytail and eleven razorback suckers were also captured. An annual report identifying catch rates and relative annual trends will be submitted to the U.S. Fish & Wildlife Service in 2010.

30) Study Title: Taxonomy and natural history of the Raphidiphoridae and Stenopelmatidae (Orthoptera) of the Colorado Plateau

Permit No.: CANY-2009-SCI-0030

Principal Investigator: Tim Graham

Purpose of Scientific Study: The taxonomy of the Orthopteran family Raphidiphoridae (camel crickets) is being revised. A number of species of *Ceuthophilus* from the Colorado Plateau were originally named from one or a few specimens collected in the early 1900's. Additional specimens are needed to re-evaluate the validity of some species designations. In addition, the taxonomy of other Raphidiphorids (e.g., the sand treaders *Ammobaenetes* *Daihinibaenetes* and *Daihinoides*) is in flux with suspected undescribed species and species' ranges unknown.

Work proposed in Canyonlands NP would involve limited collecting via the use of rolled oat trails and small pitfall traps (< 20 cm depth) in sand dune and sandy grassland areas, providing new specimens for the taxonomic work. Habitat characteristics of each collection will be described in detail and behavioral observations will be made when possible. Essentially the same situation exists with the Stenopelmatidae (Jerusalem crickets). Work is being conducted on drumming by Jerusalem crickets that appears to be involved in mating activities and thus may indicate different species even when distinguishing morphological characters have not been found. The same collecting activities will provide Jerusalem crickets as well as the camel crickets.

Findings/Accomplishments for 2009: There was no activity on this permit.

31) Study Title: Hydrology of Salt Creek, Canyonlands National Park.

Permit No.: CANY-2009-SCI-0031

Principal Investigator: Anne Brasher

Purpose of Scientific Study: Salt Creek is one of the most extensive and ecologically important riparian habitats in Canyonlands National Park (CANY). Preceding park designation in 1964, livestock traversed Salt Creek, creating a path. In the late 1940s a four-wheel drive road developed from vehicle use in the canyon. A series of road closures starting in the late 1970s has decreased total drivable mileage to a small portion of the original length. These closures have been controversial, and pit the interests of off-road enthusiasts against those of protecting the natural ecosystem. The impacts on bank erosion and vegetation are obvious but the overall effects on ecosystem structure and function, including ecosystem responses to natural high-flow events, are not well understood. The Park requires scientifically based quantification of the impacts of vehicular traffic, and the restoration potential following road closure, to evaluate and implement management strategies for the protection of Salt Creek. Our study will utilize an ecosystem approach (integrating physical, chemical, and biological parameters) for evaluating the effects of eliminating vehicles in Salt Creek. This study will synthesize data from upland systems, hydrologic measurements, geomorphological characteristics, riparian vegetation, water quality monitoring, instream habitat characterization, and

aquatic and terrestrial invertebrate assemblages, for an integrated approach to modeling of these components. The availability of a large amount of monitoring data from a number of different vital signs makes CANY an excellent location for developing tools for integrated reporting of different vital signs. This project will directly benefit the Northern Colorado Plateau Network (NCPN) as well as other Inventory and Monitoring networks across the country by demonstrating techniques for quantitative integration across vital signs (parameters) and spatial scales, and has direct relevance for Park management by demonstrating how complex ecological and physical data can be presented in meaningful ways to managers facing difficult resource decisions.

Findings/Accomplishments for 2009: Field work including collection of algae and macroinvertebrates, physical habitat characterization, geomorphology using real time kinematic (RTK) survey techniques, and mapping of riparian vegetation was completed in 2009. Plans are underway for FY 2010, and will integrate GIS, geospatial, additional geomorphic and riparian data, and biotic measurements. A draft year 1 report titled "Integrated multi-scale analyses of the Salt Creek Watershed, Canyonlands National Park, Utah" has been submitted to the Park Superintendent and the Chief of Resource Management. This report is available at the following ftp site:

<ftp://ftpext.usgs.gov/pub/wr/ut/moab/brasher/Salt Creek>.

HOVENWEEP AND NATURAL BRIDGES NATIONAL MONUMENTS RESEARCH SUMMARY 2009

1) Study Title: Soil Survey of Hovenweep National Monument, Utah

Permit No.: HOVE-2009-SCI-0001

Principal Investigator: Victor Parslow

Purpose of Scientific Study: To provide an updated soil and ecological site inventory for Hovenweep National Monument that meets National Cooperative Soil Survey (NCSS) standards and park management and planning needs.

Findings/Accomplishments for 2009: 1. Soil Survey Activities: Soil survey activities were conducted in Hovenweep NM during 2009. Soil descriptions and plant inventory data was recorded. Soil samples were collected from 30 locations. These samples have been catalogued, and are stored in the Richfield USDA Service Center. Archaeological activities: All cultural resources were successfully avoided. No cultural material was unearthed during the course of soil sample collection.

2) Study Title: Taxonomy and natural history of the Rhaphidiphoridae and Stenopelmatidae (Orthoptera) of the Colorado Plateau

Permit No.: HOVE-2009-SCI-0003

Principal Investigator: Tim Graham

Purpose of Scientific Study: The taxonomy of the Orthopteran family Rhaphidiphoridae (camel crickets) is being revised. A number of species of Ceuthophilus from the Colorado Plateau were originally named from one or a few specimens collected in the early 1900's. Additional specimens are needed to re-evaluate the validity of some species designations. In addition, the taxonomy of other Rhaphidiphorids (e.g., the sand treaders Ammobiaenetes Daihinibaenetes and Daihinoides) is in flux with suspected undescribed species and species' ranges unknown.

Work proposed in Hovenweep NM would involve limited collecting via the use of rolled oat trails and small pitfall traps (< 20 cm depth) in sand dune and sandy grassland areas, providing new specimens for the taxonomic work. Habitat characteristics of each collection will be described in detail and behavioral observations will be made when possible. Essentially the same situation exists with the Stenopelmatidae (Jerusalem crickets). Work is being conducted on drumming by Jerusalem crickets that appears to be involved in mating activities and thus may indicate different species even when distinguishing morphological characters have not been found. The same collecting activities will provide Jerusalem crickets as well as the camel crickets.

Findings/Accomplishments for 2009: There was no activity on this permit.

3) Study Title: Soil Survey of Natural Bridges National Monument, Utah

Permit No.: NABR-2009-SCI-0002

Principal Investigator: Victor Parslow

Purpose of Scientific Study: To provide an updated soil and ecological site inventory for Natural Bridges National Monument (NABR), that meets National Cooperative Soil Survey (NCSS) standards and park management and planning needs. The existing soil survey was conducted in the late 1970s and the early 1980s as part of the San Juan County, Utah, Central Part soil survey. This inventory was primarily designed as a tool for use in managing grazing lands and has been found to be too general to be useful in managing the park. Information is insufficient to model

salt movement, mitigate visitor impacts, identify and protect habitat of Threatened and Endangered species, and other park responsibilities. In 2003, representatives of the National Park Service approached the Natural Resources Conservation Service to update the existing soil surveys within Arches and Canyonlands National Parks and Natural Bridges and Hovenweep National Monuments. The Plan of Work and contract were approved in 2004. This application is seeking permission to carry out the field work necessary to complete the contract.

Findings/Accomplishments for 2009: Draft soil survey report was produced this year. No field activities were conducted.

4) Study Title: Phylogeny and Evolutionary History of *Anticlea vaginata* Rydb. (Melanthiaceae): A Hanging Garden Endemic

Permit No.: NABR-2009-SCI-0001

Principal Investigator: Tina Ayers

Purpose of Scientific Study: Sheathed Death Camas, *Anticlea vaginata* Rydb. (Liliales: Melanthiaceae) is a rare hanging garden endemic species. This research will add to the body of knowledge about Colorado Plateau hanging garden endemic plant species, assist with the ongoing endeavor to resolve the complicated taxonomy of the genus *Anticlea*, and assist agencies in future land management decisions involving this species. Knowledge of genetic diversity within populations will suggest which populations are particularly important to protect, and knowledge of gene flow will indicate what hanging gardens, if any, are interacting as subpopulations and which are completely isolated.

This research will address the following questions:

Is *Anticlea vaginata* a distinct taxon?

What is the most likely geographic and biological origin for *Anticlea vaginata*?

Is there gene flow between isolated populations of *Anticlea vaginata* and between *A. vaginata* and *Anticlea elegans*, or does there appear to be continuing diversification? Which populations of *Anticlea vaginata* exhibit the highest levels of genetic diversity, recommending them for future conservation?

What pollinators are visiting this species and which ones seem to be the most important to its fecundity?

Findings/Accomplishments for 2009: Sheathed Death Camas, *Anticlea vaginata* Rydb. (Liliales: Melanthiaceae) is a rare, hanging garden endemic plant species. *Anticlea vaginata* occurs from Dinosaur National Monument south to Arches NP, Canyonlands NP, Natural Bridges NM, and Glen Canyon NRA. There is also one population in Zion NP, one in Grand Canyon NP, and a few in northeastern Arizona on the Navajo Reservation. Very little research has been conducted on this unique species. In order to address *A. vaginata*'s validity as a species, amounts of gene flow between populations, and levels of genetic diversity, a combination of molecular data, physical characteristics, and life history traits are being analyzed. For two populations, one leaf from each of 15 individuals was collected for genetic analysis. One entire plant was collected from each of the included populations to be a voucher specimen and to be included in analyses of physical characteristics. Genetic and morphological analyses are in progress. Identifying whether or not *A. vaginata* is a good species, knowing its levels of genetic diversity and gene flow, and understanding its basic life history traits will all assist in its management.

5) Study Title: NCPN Integrated Riparian Monitoring in Natural Bridges National Monument

Permit No.: NABR-2009-SCI-0004

Principal Investigator: I&M NCPN

Purpose of Scientific Study: The National Park Service's Inventory and Monitoring Program (NPS I&M), in collaboration with 32 monitoring networks, are charged with monitoring natural resources. Vital signs represent a select set of physical, chemical and biological elements and processed of park ecosystems that are chosen to represent the overall health and condition of a park's resources. Together, the Northern and Southern Colorado plateau Networks (NCPN and SCPN) have developed conceptual models of key ecosystems and identified an integrated set of vital signs for tracking resource conditions at 35 NPS units within or near the Colorado Plateau (Thomas et al. 2004, O'Dell et al. 2005). Riparian systems are a high priority vital sign for the NCPN (O'Dell et al. 2005). Riparian systems are disproportionately high in biodiversity relative to their spatial extent due to the year-round or at least frequent availability of water. In turn, healthy and natural riparian systems serve as a predictable source of water, and function to maintain the natural diversity of riparian-adapted plants and animals across the Colorado Plateau region. Various dynamics interact to influence riparian systems. Ground-water levels, flood disturbance intensity and frequency, plant population, dynamics, and even upland conditions and dynamics collectively interact to shape the in-stream conditions and vegetative features of a riparian zone. Monitoring the status and trends in representative attributes and effects of an array of patterns and processes is an overarching goal of the NCPN Integrated Riparian Monitoring effort. This effort is intended to provide park managers with information on the variability of riparian systems, and to provide early warning of system degradation. In the latter case, monitoring information can be used to determine the potential for mitigating actions, and where such actions are implemented, monitoring efforts can contribute to understanding the effects of these actions. The full set of procedures for the NCPN Integrated Riparian Monitoring effort needs field testing for feasibility and refinement. However, the basic framework for selecting sites, for establishing stream-reach plots, for monitoring riparian vegetation, for surveying geomorphic surfaces across the riparian zone, and for measuring shallow groundwater levels and surface water stage is in place. These procedures can be implemented at this time as pilot implementation of the Integrated Riparian protocol. Pilot implementation is proposed for Armstrong Canyon in NABR. Specific objectives of the overall riparian monitoring effort are to determine the status and trends in:

- 1) the areal extent, cover, species composition and structure of riparian vegetation
- 2) exotic plant species
- 3) channel morphology of surveyed cross sections and the channel thalweg
- 4) floodplain ground-water levels and stream flow/discharge

Procedures for riparian monitoring incorporated pieces of the USGS Water Quality Assessment Program (Moulton et al. 2002) and EMAP procedures (Kaufmann et al. 1999) and were initially developed by Scott and Reynolds (draft). Further refinement has been completed by NCPN staff and by Steve Monroe and Ellen Soles of the SCPN.

Findings/Accomplishments for 2009: No activity was conducted this report year.

6) Study Title: An Investigation of North American Monsoon Variability using Instrumental and Tree-Ring Data

Permit No.: NABR-2009-SCI-0005

Principal Investigator: Daniel Griffin

Purpose of Scientific Study: The goal of this National Science Foundation-funded project is to investigate the behavior of the North American Monsoon (NAM) as a critical source of moisture for northwestern Mexico and the U.S. Southwest. Specifically, the researchers will design and apply new techniques to develop a tree-ring network that targets long-term NAM variability in the US Southwest.

Capitalizing on 30-40 existing tree-ring collections, the researchers will return to the original sampling sites to update the collections to the calendar year 2009. Re-analysis of these tree-ring collections will develop partial ring-width indices (earlywood and latewood) to reconstruct and examine the long-term variability of monsoon season precipitation, its relation with winter precipitation and widespread droughts in western North America, and to ocean/atmosphere circulation in the Pacific Ocean. The tree-ring data will also be combined with downscaled general circulation model (GCM) simulations to help understand the spatial and temporal characteristics of the NAM in the southwestern U.S. over the last few centuries as a means of providing a baseline for assessing both the instrumental records and the skill of downscaled GCMs in replicating natural variability.

We hope to update tree-ring collections at federally managed parks as part of this study, including the Mesa Verde, Guadalupe Mountains, and Bryce Canyon National Parks, as well as the Natural Bridges, Chiricahua, and Walnut Canyon National Monuments. These properties have proven critical to tree-ring research over the past century, serving as unique refugia for old-growth Douglas-fir forests. The tree-ring chronologies developed at these sites are among the most important in the US Southwest, and updating the existing tree-ring collection to the calendar year 2009 will allow the to be included in our detailed analyses.

We request permission to re-visit the tree-ring site at White Canyon in order to non-destructively sample increment cores from 20 to 30 living Douglas-fir trees. This is one of the northernmost sites in our proposed tree-ring network (<http://monsoon.ltrr.arizona.edu/sites.html>), and we sincerely believe it to be critical for examining variability around the northern extent of the monsoon in the Southwestern United States.

The broader impacts of this project include a strong educational mentoring portion and an equally strong intellectual portion. The research will help support graduate and undergraduate student involvement in a cutting-edge paleoclimate project whose goal is to use tree-rings science to better inform regional water resource planners. It is our hope that the results of this study, specifically a more detailed seasonal climate history, would be of interpretive and intellectual relevance to visitors and other research projects being conducted in the Natural Bridges National Monument. Upon permission from the park, the specimens would be accessioned under the NPS system and permanently archived at the University of Arizona Laboratory of Tree-Ring Research.

Findings/Accomplishments for 2009: In July 2009, Laboratory of Tree-Ring Research (LTRR) researchers Daniel Griffin, Connie Woodhouse, Mark Losleben, and Victor Major visited Natural Bridges National Monument to collect new tree-ring specimens from the original sampling site in White Canyon where Jeff Dean of the LTRR had made tree-ring collections in 1972 and 1989. Off trail, just below the upper level bluff of White Canyon, two increment cores were non-destructively sampled from each of nineteen living Douglas-fir (*Pseudotsuga menziesii*) trees. Meeting the stipulations prescribed by the NPS, no more than ten percent of trees in a given stand were sampled. Back at the LTRR in the fall of 2009, these specimens were inventoried and prepared (mounted and sanded) for microscope analysis and

cross dating using standard tree-ring techniques. Also in 2009, the archived tree-ring collections from the site was obtained from the LTRR archives and prepared for earlywood and latewood measurement.

In 2010, the collections made in 2009 at Natural Bridges National Monument will be analyzed and cross-dated using the methods of dendrochronology. Tree-ring specimens from both the new and archived collections will be measured for earlywood- and latewoodwidth. The newly completed chronology from White Canyon will include over 100 radii from approximately 50 trees and will extend from 1347-2008. In 2011, this chronology, along with the other 50 or so in the network, will be used in analyses geared toward reconstructing spatiotemporal variability in monsoon precipitation across the region, and a final report on the projects findings will be prepared for the NPS.

7) Study Title: Taxonomy and natural history of the Rhaphidiphoridae and Stenopelmatidae (Orthoptera) of the Colorado Plateau

Permit No.: NABR-2009-SCI-0006

Principal Investigator: Tim Graham

Purpose of Scientific Study: The taxonomy of the Orthopteran family Rhaphidiphoridae (camel crickets) is being revised. A number of species of *Ceuthophilus* from the Colorado Plateau were originally named from one or a few specimens collected in the early 1900's. Additional specimens are needed to re-evaluate the validity of some species designations. In addition, the taxonomy of other Rhaphidiphorids (e.g., the sand treaders *Ammobaenetes* *Daihinibaenetes* and *Daihinoides*) is in flux with suspected undescribed species and species' ranges unknown.

Work proposed in Natural Bridges NM would involve limited collecting via the use of rolled oat trails and small pitfall traps (< 20 cm depth) in sand dune and sandy grassland areas, providing new specimens for the taxonomic work. Habitat characteristics of each collection will be described in detail and behavioral observations will be made when possible. Essentially the same situation exists with the Stenopelmatidae (Jerusalem crickets). Work is being conducted on drumming by Jerusalem crickets that appears to be involved in mating activities and thus may indicate different species even when distinguishing morphological characters have not been found. The same collecting activities will provide Jerusalem crickets as well as the camel crickets.

Findings/Accomplishments for 2009: There was no activity on this permit.